

An Auction-Based Approach for Composite Web Service Selection

Mahboobeh Moghaddam^{1,2}

¹ School of Information Technologies, University of Sydney, Australia

² National ICT Australia (NICTA), Australian Technology Park

Sydney, NSW 1430, Australia
mahboobe@it.usyd.edu.au

Abstract. Web service composition (WSC) offers a range of solutions for rapid creation of complex applications by facilitating the composition of already existing concrete web services. One critical challenge in WSC is the dynamic selection of concrete services to be bound to the abstract composite service. In our research, we identify and elaborate on the challenges involved on developing a market-based mechanism for composite service selection. We propose a *combinatorial procurement auction model* as a useful approach to research service selection, in order to overcome the limitations of the current optimization-based and negotiation-based solutions. The proposed auction model supports dynamic pricing for the offered web services, enables the providers to express their preferences more fully, and creates the incentive for the providers to be truthful about the offered prices.

Keywords: web service composition, service selection, combinatorial procurement auction.

1 Introduction

One of the critical research challenges in realizing the vision of agile and collaborative software development using web services is *Web Service Composition* (WSC) which involves creating a composite service by combining different web services to provide a new value added service. The composite service is usually defined at an abstract level as a high level business process (BP) which comprises a set of tasks, along with the control and data flow among them. Each task has a clear description of the required functionality, and the non-functional properties, aka Quality of Service (QoS) attributes, such as execution time, availability, down time, security, and price.

In WSC, composite web service selection refers to the process of choosing a group of web services which can execute the tasks in a BP. In today's Internet, tens of web services with similar functionality exist online which are offered at different levels of quality and price. The aim of composite service selection is to choose those services that best match service requester's requirements while simultaneously maximizing the user utility in terms of the quality of service and cost. The two current approaches to composite service selection suffer from limitations such as static QoS profile and the

need for a complex decision model. To address these problems, this research aims to develop an auction-based model for service selection. As a market-based mechanism, an auction allows for dynamic pricing which is critical for web services.

The remainder of this paper is as follows: Section 2 discusses the research problem and challenges. Section 3 outlines the proposed approach, a preliminary mathematical model, and related work. Section 4 provides the conclusion and our research plan.

2 Research Problem and Challenges

A natural approach to composite service selection is to map this problem to an optimization model and to solve it using existing optimization methods, e.g. Integer Linear Programming, or Genetic Algorithm. Research in this area includes but not limited to [1-3]. However, optimization-based approaches require the service providers to publish their web services with predetermined values for the QoS attributes. This requirement limits the service requester to have an approach of take-it or leave-it toward the offered services. Moreover, the fixed profile is not very realistic in light of the relatively dynamic environments that characterize the selection and composition of web services. This problem has been referred to as defining the QoS profile in a static non-negotiable, non-configurable manner [4].

To address the static QoS profile, a number of service selection approaches consider a flexible and negotiable quality profile for a service, i.e. negotiation-based service selection [5-7]. In this approach, automated negotiators negotiate on behalf of the service providers and requester. The automated negotiators require a complex decision model which makes their application in real world settings somewhat impractical, at least for the near future. Moreover, the dynamic aspects of negotiation approaches complicate the problem of finding globally optimum solutions.

To address these problems, this research aims to develop a model based on *auction theory* for the *composite web service selection problem*. Auctions are known to be the most widely used mechanism for dynamic pricing [8] which is critical for products such as web services that are characterized by dynamic execution environments (in terms of the provider's available resources), and users with different and changing demands. This is an improvement over totally pre-determined value for the price, as in the optimization-based approaches. In addition auctions can be designed so that complex decision models are not required.

More specifically, this research seeks to answer the following questions: (1) What are the specific requirements for auctions in the WSC domain and how do these differ from other domains such as transportation, communication networks, and resource scheduling? (2) How can we compare different auctions to elicit these requirements? What are the dimensions of this comparison? (3) What are the necessary elements for developing an auction model to solve composite service selection? (4) What are the desirable auction properties for the context of our research? e.g. incentive compatibility, Pareto efficiency, economic efficiency, or maximizing auctioneer revenue.

In our research, we face a number of interesting challenges. First, as auction theory is rather a broad area with extensive research from different communities, one challenge is to integrate and adapt models and methods based on an inter-disciplinary approach drawing on economics, game theory and theoretical CS. Second, we do not have an existing baseline to validate our answers to the research questions. The challenge is to develop the validation criteria alongside the answer to each question. Finally, since the current literature is quite limited, our proposed solution must be evaluated using innovative approaches. The challenge is to define the comparison criteria. We can draw on other areas, such as negotiation-based service selection, and develop similar evaluation metrics, e.g. utility of the service requester.

3 Combinatorial Procurement Auction

In a reverse or procurement auction model for composite service selection, the service requester is the auctioneer and the service providers bid for offering services for the tasks in the BP. Our interest is in a specific type of the auction, called *combinatorial auction*. In this auction, multiple distinct items are auctioned simultaneously and the bidders can bid over a combination of items, or *bundles*. Bundling enables the bidders to express their preferences over the items more fully, which leads to economic efficiency and greater auction revenue [9]. Bundling is particularly important when bidders have preferences not just for specific items but for item bundles due to the complementarities or substitutability effects that exist among the items [10].

In WSC domain, services that are bound to a BP are inter-dependent on factors such as execution time, recourses consumed, and data. These dependencies make it attractive for service providers to provide services for dependent tasks as a bundle. Offering services in bundles helps them internalize some of the service execution cost, and consequently leads to offering a lower price for the bundle. From the requester's point of view, this enables requesters to exploit the modular structure that may exist when decomposing the abstract BP.

The design of an auction includes two key, inter-dependent elements. The first element, Winner Determination Problem (WDP), decides which bidder gets what items. The second element, pricing schema, determines the price the bidders should pay (general auctions), or will receive (a procurement auction). When designing these elements, the primary design objective is to achieve a mechanism with desirable properties [11]. One of the most important of these properties is *incentive-compatibility* or *truthfulness*. In a truthful auction, the dominant strategy for bidders is to bid truthfully since this gives them the highest utility [12]. The incentive for truthful bidding is provided through the design of appropriate pricing schema.

To model composite service selection as a combinatorial procurement auction, we have designed the two elements so that the achieved mechanism is incentive-compatible. In the WDP part, we mapped the composite service selection to an Integer Linear Programming problem. The objective function is to minimize the cost for the service requester, subject to quality constraints. For the pricing schema, we draw on the Vickrey-Clarke-Groves (VCG) model [13]. VCG is the best known auction for

multiple items that is incentive-compatible. Its objective function is to maximize the economic efficiency which we have mapped to minimizing the cost for the auctioneer, following [8, 10]. In VCG, the pricing schema for each winning bidder defines a price which is independent of the winning bidder's bid.

3.1 Combinatorial Procurement Auction Model

Let B be the set of all received bids from all providers, with an arbitrary member denoted as b_i where $i \in I$ (set of bid indices), $I = \{1, \dots, N\}$ and N is the total number of all received bids. Let $Task$ be denoted as the set of all tasks in the business process, with an arbitrary member defined as $task_j$ where $j \in J$ (set of task indices), $J = \{1, \dots, M\}$ and M is the total number of tasks in the BP. Each bid b_i is defined as $b_i = (T_i, c_i, \vec{q}_i)$, where c_i is the cost of providing service(s) for the task(s) in the set T_i ($T_i \subseteq Task$) with the offered quality vector of \vec{q}_i for the service(s). For the current model, we consider two quality attributes in the quality vector; availability and response time denoted as v_i and r_i respectively; i.e. $\vec{q}_i = (v_i, r_i)$.

The objective is to minimize the cost for the service requester, equation (1), subject to quality constraints. Equation (2) ensures that each task is assigned to no more than one provider. To get the unique assignment, we defined matrix $A_{I \times J}$ with an arbitrary element of a_{ij} which is 1 if T_i (in b_i) includes $task_j$ and 0 otherwise.

$$\min. \quad \sum_{i \in I} c_i * z_i \quad (1)$$

$$s.t. \quad \sum_{i \in I} a_{ij} * z_i = 1 \quad \forall j \in J \quad (2)$$

$$\sum_{i \in I} \ln(v_i) * z_i \geq \ln(V) \quad (3)$$

$$\sum_{i \in I} r_i * z_i \leq R \quad (4)$$

Inequalities (3) and (4) define the quality constraints for availability and response time, where V and R are the service requester's acceptable minimum availability and maximum response time levels for the composite service (the availability's aggregation function is linearized using a logarithm function [2]). The decision variable is denoted as z_i to be 1 if b_i is a winning bid and 0 otherwise.

The VCG pricing schema is defined as follows [8]:

$$p_k = \sum_{j \in B \setminus B_k} c_j z_j^{*k} - \sum_{j \in B \setminus B_k} c_j z_j^* \quad (5)$$

In the equation (5), z_i^* are the decision variable values for the optimal solution (z_i^* is 1 for the winning bid, and 0 for others), and z_i^{*1k} are the variable values of the optimal assignment, if we remove the bids of provider k from the set of bids. Let $B_k = \{b_i \in B | b_i \text{ is a bid from bidder } k\}$. We define $B \setminus B_k$ as the set of indices of all bids without the bids of provider k . The price p_k to be paid to the winning bidder k is the result of subtracting the cost of all other bids in z_i^* from the sum of the cost of bids in z_i^{*1k} .

3.2 Related Work in Auction-Based Service Selection

There is limited research on the application of dynamic market mechanisms such as auctions for service selection. The combinatorial procurement auction discussed in [14, 15] is in fact another optimization-based approach with the objective function as maximizing the composite service's quality, subject to a budget constraint [14], or minimizing the cost subject to quality and interface matching constraints [15]. The main innovation is that, in the IP formulation proposed in the papers, the service provider is able to offer services for more than one task in the BP. However, the proposed technique does not discuss two critical aspects of a typical auction, namely pricing schema and design objectives such as incentive-compatibility property.

A multidimensional procurement auction is proposed in [16] for trading composite services. The objective is to maximize the joint utility of the service requester and providers and the mechanism is incentive compatible with respect to all the dimensions of a bid (quality and price). However, the proposed auction is not combinatorial and the service requester cannot define any constraint for the composite service required quality or budget. In addition, every service provider needs to prepare a bid for each combination of her service with possible precedent services from other providers. This is not trivial especially in the domain of web services and Internet, where it is difficult for a provider to obtain enough information about others.

4 Conclusion and Research Plan

In this research, we elaborate on the challenges involved in developing an auction-based solution for composite service selection. As the first step, we proposed a combinatorial procurement auction-based model and discussed it in terms of the WDP element, and the pricing schema. Our design ensures that the achieved mechanism is truthful, which prevents the bidders from spending resources learning about other bidders' values or strategies [13].

Our future work includes extending the current model along two directions. The first direction is extending the model to include requirements that are specific to the WSC domain. For example, considering the multi-attribute nature of web services offer, one possibility is to extend the current model to include other service's quality attributes as part of the objective function, which will affect the VCG pricing schema. Second, we will study the relation between an auction design objective and different environmental settings that characterize a WSC problem. These environmental settings include factors such as how severe the QoS requirements are, or the BP

popularity (how many providers are willing to offer service for its tasks). We plan to design and carry out a number of simulation and laboratory experiments with human participants as service providers who bid for bundles of services, and a prototype system as an independent auctioneer that implements different auction models. The outcome of the experiments will be a set of recommendations and strategies that will specify the appropriate auction models for web service selection under different conditions.

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